Aerosol Concentrations and Fluxes near the Ocean Surface during the Rough Evaporation Duct (RED) Project

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LONG-TERM GOALS

The overall aim of this project is to improve substantially the parameterisation of sea spray particulate fluxes for a wide range of environmental conditions. To meet US Navy needs for more accurate predictions of aerosol loadings, the underlying physical and chemical processes determining aerosol formation and evolution in the maritime environment must be defined. Progress is already being made with the formulation of aerosol models, such as NAAPS, which aim to provide a mesoscale aerosol predictive capability. However, to date, these models have concentrated upon the smaller accumulation mode aerosol components ($r < 1\mu m$) of importance in defining general air mass turbidity and radiative impacts. Close to the sea surface and in localised regions, these models must be extended to incorporate predominantly wind-driven sea spray generation and surf zone aerosol processes to deal with current and future Navy requirements. In addition to the primary purpose of this work to address the sea spray source function, as well as to provide detailed atmospheric particulate measurements in order to permit closure between electro-optical propagation and aerosol properties in the RED project.

OBJECTIVES

The development of lightweight, robust and relatively inexpensive optical particle counters based upon modified Met One aerosol sensors has been pursued with a view to deploying a number of units on R/P FLIP. Considerable effort has been expended, using a laboratory test rig and software analyses, in understanding the performance of these units, and in developing a microprocessor-based data acquisition system in order to optimise the performance of these devices. Special consideration has been given to dealing with particles of differing chemical composition (and, hence, different refractive indices). Unfortunately, the loss of the services of one of the key team members, due to severe illness, at a late stage in this development, meant that the instruments could not be produced in time for the RED project. Accordingly, the decision was taken to proceed with a more limited measurement campaign during the project using existing optical particle counters.

APPROACH

Met One (a division of Pacific Scientific) manufactures a range of compact particle counting instruments based around a very small scatter cell measuring approximately 7 x 3 x 3cm, including the circuit board containing the laser diode power supply and signal preamplifiers. Despite its small size, this unit operates with a sample flow rate of about 50ml/s, which is substantially greater than many, much larger particle

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spectrometers. As supplied in its Model 227B unit, the instrument has a lower sensitivity of 0.3μm diameter, an upper cut-off above 5μm, and weighs less than 1kg including internal batteries. However, as supplied, this unit provides only two particle counting channels, namely, all particles above 0.3μm, and another channel for particles above a size-selectable range from 0.5 to 5.0μm, thereby limiting its usefulness for atmospheric studies.

The Leeds group has been working with this unit to develop a compact, robust, lightweight and relatively inexpensive instrument for use in a number of applications where these properties are especially beneficial. In addition to Professor Michael H Smith, who leads the group, the team comprises Mr Martin K Hill and Dr Barbara J Brooks. Mr Hill has been jointly responsible for the concept and is undertaking the design and development of the microprocessor-based control and data acquisition unit. Dr Brooks has adapted Mie code software for analysing the performance characteristics of the device and has undertaken testing of the laboratory-based prototype.

Starting with the scatter cell itself, a small circuit board has been designed which, in addition to the appropriate control, data storage and transmission electronics, contains a multi-channel pulse height analyser. Initially, an 8- or 16-channel analyser was envisaged but this design has evolved to a 256-channel unit, which may be grouped into a smaller number of size bins, in normal operation. Including the small pump to draw sample air through the instrument and a simple air intake system, but with an external power supply, these devices should weigh around 0.5kg, with a component cost below about $2000 and a modular design permitting simple and fairly rapid repair.

The scatter unit itself may be operated remotely or locally by means of a circuit board, which has been designed to implement the appropriate control, data storage and transmission electronics, and also contains a multi-channel pulse height analyser. Initially, an 8- or 16-channel analyser was envisaged but this design has evolved into a 256-channel unit, with a programmable non-linear transfer function and a basic resolution of 2mV. A small sampling pump, with programmable flow control, draws sample air through the instrument and, together with a simple air intake, completes the system. With an external power supply, these devices should weigh around 0.5kg, at a component cost below about $2000. The modular design will permit simple and fairly rapid repair.

Laser scattering instruments generally exhibit a multi-valued response for particles around the wavelength of the laser illumination, the precise location of which depends upon the refractive index (and hence the composition) of the particulate material. Having a 256-channel analysers permits the adjustment of the size bin thresholds in order to overcome these sizing difficulties, either on-line or in post-processing of the gathered data. In addition, the use of a microprocessor-based control and data processing unit allows user-selectable transfer characteristics to be chosen so as to optimise the instrument performance. Tests suggest that careful adjustment of the sample flow rate and other features of the unit should enable the manufacturer's limited size range, to be extended, perhaps from as low as 0.15μm to over 10μm in radius.

Additional work has been undertaken to design a sample heater, so that the system may be operated as a volatility unit for studying the chemical composition of the aerosol. One of the many possible deployments for the sensors is on a helium balloon platform, which precludes the use of electrical heating. The current design uses a heater system based on propane gas, with the temperature being controlled by admixture of cold air to the hot (>600ºC) air produced by the heater. Sample volatilisation takes place in a stainless steel tube prior to entering the optical sampling unit.

Furthermore, with the addition of a front end consisting of a chamber to saturate the sample air with butanol vapour, followed by a simple electronic chiller, the unit could be operated in a 'CPC' mode, with sensitivity to particles as small as 0.01μm. Work on this aspect of the device is at a preliminary stage.

WORK COMPLETED

The size and layout of the basic scatter cell unit is shown in Figure 1. The black scatter cell has inlet and exhaust ports, with the aluminium disk covering the scatter cell parabolic mirror, which may be removed readily for cleaning purposes. The infra-red laser illuminates the particles at 90º to their flow with the photo-detector being mounted orthogonally to the beam on the circuit board below. This circuit board houses the laser photo-diode power supply as well as the initial signal conditioning electronics.

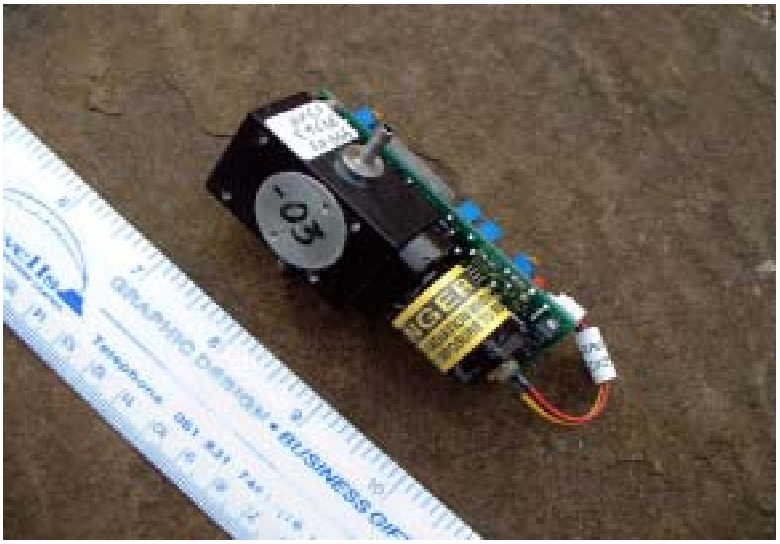

Figure 1: Photograph of the instrument scatter cell (see text for details)

Mie scattering code has been adapted in order to evaluate any multi-valued features in the scatter cell response and the results of these calculations are presented in Figure 2, with results for the Particle Measuring Systems FSSP-100 probe shown for comparison purposes.

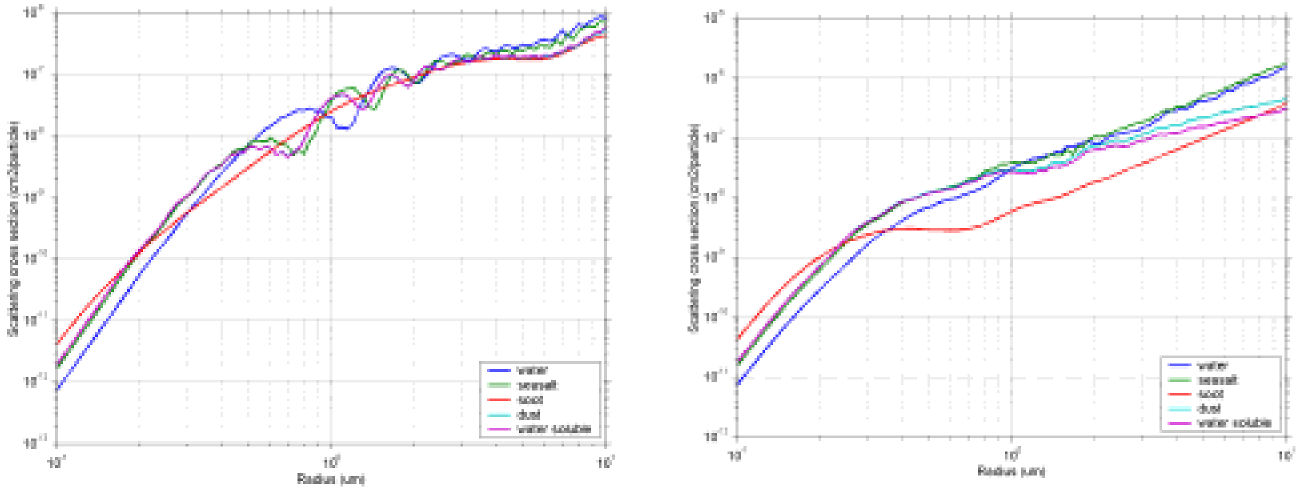

Fig. 2: Scatter cross sections of particles for FSSP (left) and Met One (right) particle counters

It may be noted that the infra-red wavelength employed in the Met One is somewhat less sensitive to refractive index variations in aerosol materials (apart from soot) than the HeNe laser wavelength used in the FSSP. The optical geometry of the unit affect the amount of scattered light detected, and the non-linear amplifier gain further modifies the instrument response. Taking all these factors into account, the output characteristics of the device for laboratory aerosol particles is shown in Figure 3 below.

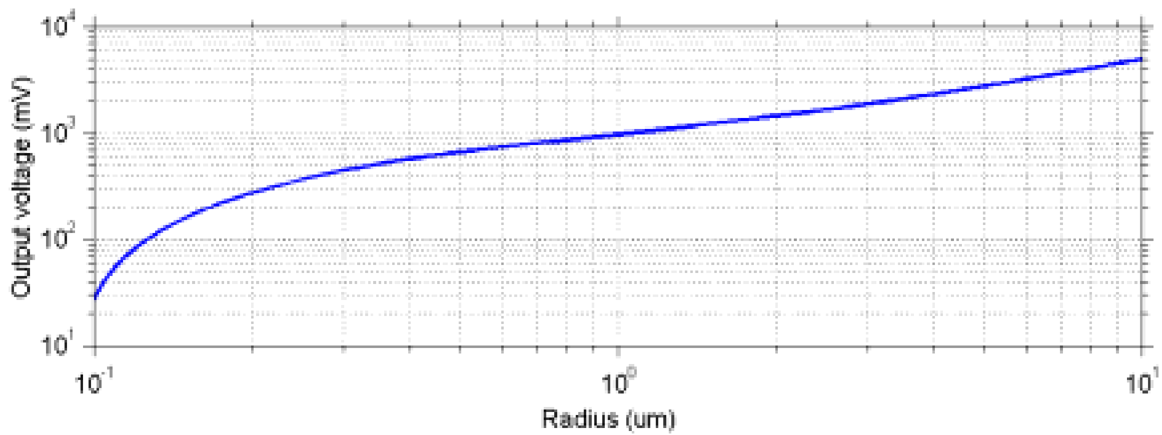

Figure 3: Output signal from the scatter cell unit as a function of particle size.

Finally, the performance of the laboratory-based prototype has been compared with a Particle Measuring Systems ASASP-X for the prevailing laboratory aerosol particles and the results are shown in Figure 4 below.

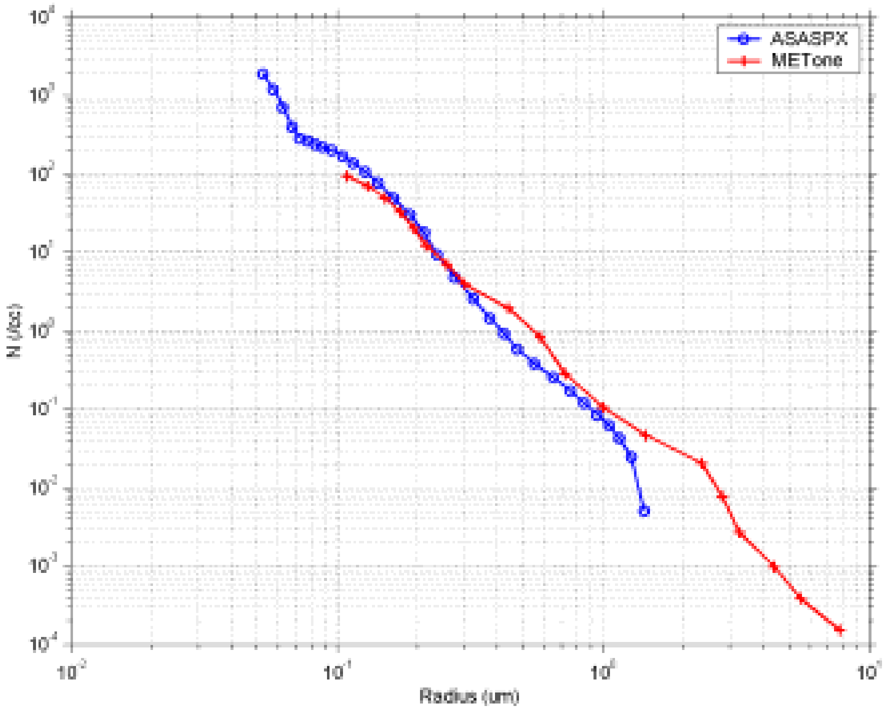

Figure 4: Comparison of the laboratory-based prototype with a PMS ASASP-X instrument for laboratory aerosol particles

RESULTS

As indicated previously, it proved impossible to have the requisite Met One optical particle counters ready in time for the RED project and, thus, measurements were undertaken using existing aerosol equipment provided by SPAWAR to provide a more limited set of observations. This instrumentation consisted principally of two PMS particle counters, an FSSP ($1 < r < 16\mu m$) and a PCASP ($0.05 < r < 1.5\mu m$). These devices were mounted at the far end of a boom, approximately 20m long, positioned on the starboard side of R/P FLIP about 15m above mean sea level. Although the orientation of these probes with respect to wind direction was fixed, the sampling efficacy of these probes was not compromised, as variations in wind direction throughout the experiment did not exceed ±10°. An aspirated and heated 10m intake supplied, to both a TSI Aerodynamic Particle Sizer and an Integrating Nephelometer, a dried aerosol particle stream sourced from a location 2m above the tallest point of the platform hull. As the project has only just terminated, results presented here should eb regarded as extremely preliminary.

In very general terms, the particle loading seen by all probes was very low for the vast majority of the project, with PCASP concentrations of 90 – 150 /cc before dawn (06:00 local) and after 17:00 local. There appeared to be slight increases in concentrations (PCASP up to 200) during the daylight hours but it is unclear yet as to whether these were photochemical in origin or due to the increased wind speeds seen during the day. Throughout the project, wind speeds varied between 10 and 15 knots, while the direction varied between 90 and 100°. Sea temperature was of the order 26 °C while air

temperature ranged from about 30 -35°C. Relative humidity extended from 75 to 83 % with little diurnal variation.

Monday 10 September through to Wednesday 12 proved to be of greater interest. Although there was no perceptible change in the meteorological conditions (wind speed and direction, temperature, and relative humidity), aerosol concentrations were observed to undergo a two- to three-fold increase. PCASP (06:00 10/09/01) 270 /cc (14:00 10/09/01) 290 /cc, (11/09/01 02:00) 280 /cc (11/09/01 15:00) 158 /cc. The reason for these changes is uncertain at the present time.

IMPACT/APPLICATION

The instruments under development have the benefit of very small size and relatively low cost which will promote their application on tethered balloons, in model aircraft and in situations where physical risks to the instruments precludes the use of more expensive commercial optical particle counters.